

SELF-CONSISTENT GAS AND STELLAR DYNAMICS OF DISK GALAXIES: A PROBLEM OF DARK MASS

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Abstract

We present¹ results of numerical modeling made for the galactic stellar and stellar-gas disk embedded in the spherical halo and bulge. The stellar disk is simulated by N-body system, the equations of hydrodynamics are solved by TVD-method. We used TREEcode-algorithm for calculation of a self-gravity in stellar and gaseous components. The possibility of bars birth in a hot stellar disk because of gravitational instability of a cold gas component is investigated. The conditions of occurrence lopsided-galaxies from a axisymmetric disk as a result of gravitational instability are explored. The self-consistent models of double bars are constructed and the dynamical stability of these structures is discussed.

Keywords: galaxies, halo, N-body, gasdynamics, lopsided, double bars

1 Introduction

Dynamics of many structures in disk galaxies is considerably determined by spherical subsystem properties and, in particular, by characteristics of density distribution of dark halo in stellar disk limits.

The bar formation because of global bar-mode instability is impeded, if halo mass inside of optical radius surpasses disk mass $M_h \lesssim (1 - 1.5) \cdot M_d$ [1, 10]. On the other hand, the observations data and N-body simulation give estimates $M_h/M_d > 1.5$ for some galaxies [4, 5]. Gas component is cold because of radiative cooling and can be gravitationally unstable. The unstable modes in massive gas disk are capable to generate the bar even in the hot stellar disk in case of a high dispersion of stars velocities and at presence of the massive halo.

A asymmetrical spiral structure (one-arm) and bar displacement concerning disk centre are typical distinctive features of a series SBcd–SBm galaxies (Magellanic type). These properties are observed at LMC, NGC 55, 925, 1313, 1744, 4490, 4618, 4625 etc. [8, 9, 13]. The formation mechanism of the displaced bar and other features of lopsided-galaxies can be caused by preferred growth of one-arms modes in gravitationally unstable disk and by subsequent interaction of these perturbations with a bar-mode at a nonlinear stage [12]. The late type galaxies contain more gas, than early type objects. Therefore question on influence of gas on the bar displacement and asymmetry in disk structure requires of special study.

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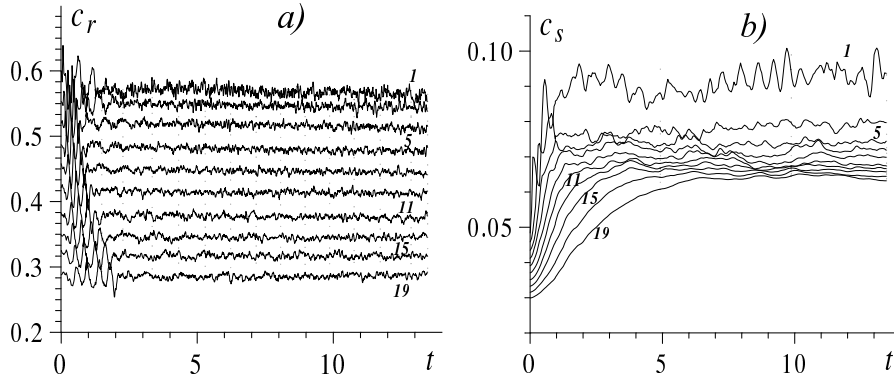


Figure 1: Time dependences of the dispersion of stars radial velocities c_r (a) and sound speed of gas c_s (b) on various radii (curve 1 — disk center, 19 — disk periphery).

The small-scale asymmetrical structures at disks center are very important for understanding of a phenomenon of nuclear galactic activity. The double bars can deliver gas to a active nuclei [11]. The photometric data are the basic evidence about presence of the second inner bar at approximately 70 galaxies [6]. The self-consistent models of double bars were studied by the N-body method [2, 3]. Key problem of double bars is the question on dynamic stability of these systems.

2 Modelling

2.1 The numerical model of stellar-gas disk

The 3D stellar disk simulation is based on N -body model, taking into account an external field of the rigid matter distributions in bulge and halo. The gas disk model is constructed on the non-viscous equations of gasdynamics, and is complemented by gravitational forces on the part of stellar disk, spherical subsystem, and gas self-gravity also.

The gas galactic disks are cold, as the sound velocity c_s is much less than the dispersion of radial velocities in stellar disks c_r . The radiative losses in the equation on energy are defined by quantity Q^- :

$$Q^- = A_c \frac{(c_s^2 - c_{s1}^2)^\alpha}{(c_{s2}^2 - c_s^2)^\beta} \cdot \varrho^2 \text{ for } c_s > c_{s1} \quad (Q^- = 0 \text{ for } c_s < c_{s1}), \quad (1)$$

ϱ — density, parameters A_c , c_{s1} , α , c_{s2} , β are free. The cooling of gas strongly grows in the case $c_s \rightarrow c_{s2}$, therefore restriction $c_s < c_{s2}$ is carried out always. We solved hydrodynamical equations by the method TVD-E. The self-gravity account in gas and stellar disks is based on TREEcode. We simulated disks with an exponential profile of surface density and radial scale L .

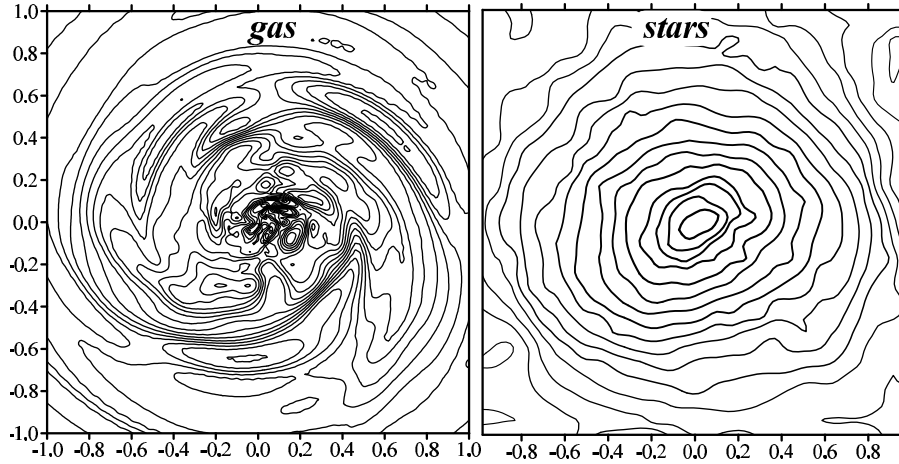


Figure 2: The gravitational instability of gas is the reason of bar formation in central area of the hot stellar disk. The isolines of a surface density are shown.

If the stellar disk is on threshold of gravitational stability, small mass of cold gas component does not give to an additional heating of the stellar system (fig. 1). The gas mass is equal $M_g = 0.08 \cdot M_d$ inside the stellar disk in this model. And the massive halo ($M_h = 3M_d$) forbids the bar formation, as in stellar component (which besides is hot), and in gas disk.

2.2 The stellar bar formation because of gravitational instability in the gas disk

Let's consider models with halo mass $M_h = (1 \div 2.5) \cdot M_d$. In all cases the initial dispersion of star velocities and the massive halo provide gravitational stability of the stellar disk in absence of gas. The account of gas can qualitatively change evolution of system.

The radiative cooling provides cold, gravitationally unstable state of gas component, it gives in formation in gas of non-axisymmetric structures, which in turn generate disturbances in the stellar disk (fig. 2). There is the prompt bar formation in the stellar disk because of gravitational gas instability, if the models contain a lot of gas. It is important, that the instability of gas can generate the bar in hot stellar disk (fig. 3), when Toomre's parameter exceeds $Q_T = c_r/c_T \gtrsim 2$ in the region $r \leq L$. Such disks are stable without gas.

2.3 Lopsided-galaxies

Let's consider key influence of the gas component on effects of bars displacement and occurrence of asymmetry in isolated disk structure in the whole. The initial distribution of dispersion of stars velocities and the parameters of spher-

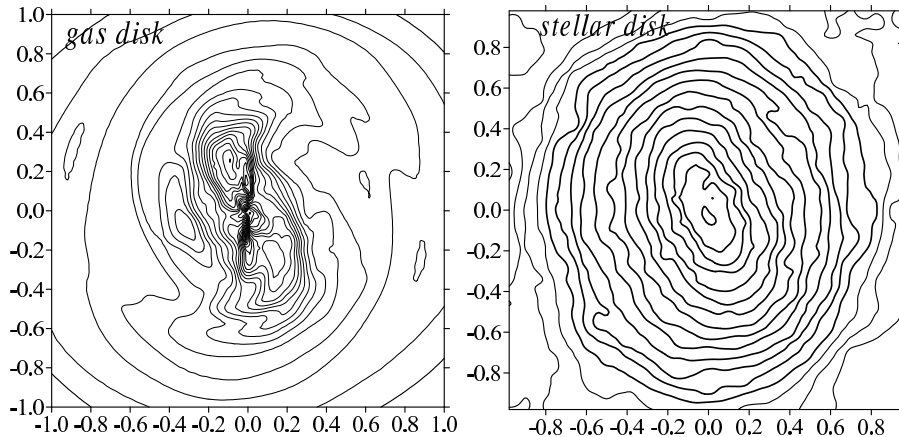


Figure 3: The isolines of surface density of stellar disk (left panel) and gaseous disk (right panel) after 5 rotation periods of outer part of disk. The standings of shock waves are well visible in region of the bar.

ical subsystem suppose the slow formation of bar without the account of gas component. However the amplitude of one-arm harmonic ($m = 1$) is very small and formation of the lopsided-disk does not occur.

The formation of harmonic $m = 1$ is possible in a massive cold gas subsystem. The nonlinear interaction of a one-arm mode and bar-mode ($m = 2$) in the gas disk is the reason of asymmetry of stellar disk also. The results of simulation in case of $M_{gas} = 0.47 \cdot M_d$ in limits of $r \leq 4L$ are shown in fig. 4. With growth of relative gas mass we have amplifications of the bar displacement concerning centre of disk and power of spiral structure asymmetry. The considered mechanism of formation of lopsided-galaxies is most effective in case of small halo mass and if the halo scale exceeds the exponential disk scale in 2 times and more.

2.4 The problem of double-bars formation

The bar formation requires not a hot initial disk and the halo mass $M_{halo} + M_{bulge} \lesssim 2M_{disk}$ at halo scale a $(1 - 4) \cdot L$ (L — exponential disk scale). The birth of inner bar in numerical models occurs at presence of enough massive bulge ($M_{bulge} \gtrsim 0.3M_d$). In Fig.5, we show the distributions of surface density logarithm $lg(\sigma)$ at the different time moments in model with $M_h = M_d$, $M_{bulge} = 0.6M_d$, in which at particular stages there are structures such as double bars.

The features of a kinematics of disk central region ($r < 2L$) at a stage of double bar are shown in a fig.6. The field of velocities in the stellar disk is the important information on existence of inner bar. The radial velocity U demonstrates four-areal structure, both for inner bar, and for primary bar.

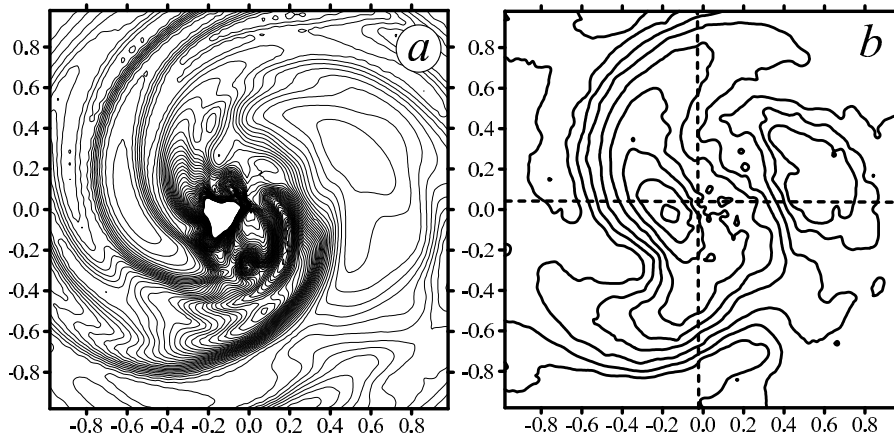


Figure 4: The isolines of surface density of gas (a) and stellar (b) components are shown in the case $M_h/M_d = 1$, $M_{gas}/M_d = 0.47$. The initial Toomre parameter is equal $Q_T \gtrsim 1.3$ for the stellar disk in region $r \leq 2L$.

The lifetime of double-bar does not exceed 1–2 rotation periods in the most ideal model of the stellar disk. The bending instability of disk and/or bar is the important factor of double-bars decay. The additional account of gas qualitatively changes result. The double-bars are not forming in self-consistent numerical stellar-gas models because of additional nonlinear perturbations. External asymmetrical potential (the tidal influence from the massive companion) gives similar result and such models do not give double-bars also. The conclusion about a dynamically fast phase of existence of “double bar” is agreed with work [7], that the secondary bar not is real dynamically allocated structure at observed galaxies, and represent a combination of objects with various morphology.

3 Conclusions

1. The bar formation in the hot gravitationally stable stellar disk can be generated by the unstable cold gas disk. This mechanism generates the bar even in case of the massive halo $M_h/M_d \simeq 1 - 2$.
2. The account of gas component strengthens the formation of asymmetrical structures (lopsided, mode $m = 1$) in a isolated disk as a result of gravitational instability in case of halo with small mass and large scale in comparison with a disk scale. At Magellanic type galaxies the relation of halo mass to disk mass in limits of optical radius on the average is less, than at systems of early types.
3. The self-consistent models with the double bar are extremely unstable in relation to the various factors (transient spiral waves in a disk plane, bar warps, bending instabilities of a disk, tidal influence, gas component) at initial stages

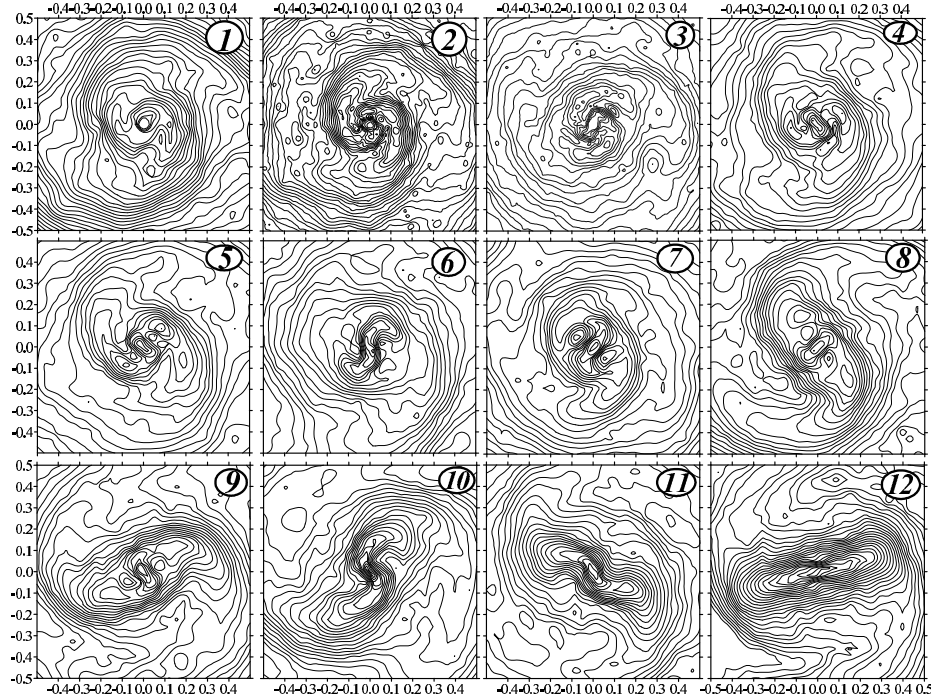


Figure 5: The surface density distribution in different time (4, 5, 7, 8, 9 — double bars).

of evolution. The conclusion about a very short phase of existence of systems such as “double bars” (transient nature) is made and similar structures can arise under special conditions at an initial stage of bar-mode development.

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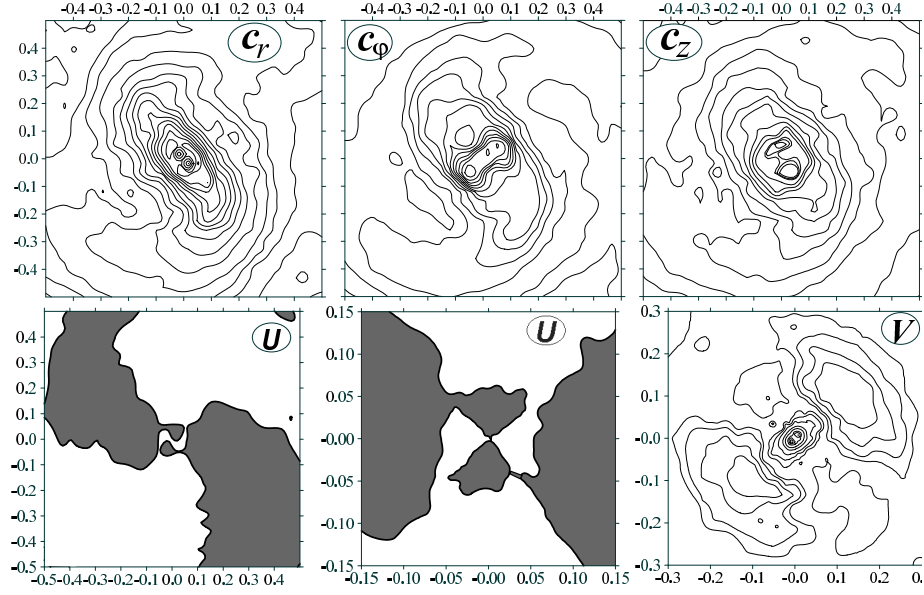


Figure 6: The distributions of the dispersions of velocity components (c_r , c_ϕ , c_z) and the isolines of azimuthal velocity V and radial velocity U . The areas of positive and negative radial velocity are shown by different shading for the main and inner parts of the stellar disk.

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